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# EXPERIMENTAL STUDIES OF FALLOUT SHELTER VENTILATION REQUIREMENTS


by

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REVIEW NOTICE

This report has been reviewed in the Office of Civil Defense and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Office of Civil Defense.

## FOREWORD

The forced ventilation tests reported herein were conducted by the General American Research Division (GARD), formerly the MRD Division, of the General American Transportation Corporation, Niles, Illinois, during the period from October 1962 to September 1964 under the Office of Civil Defense Contract No. OCD-OS-62-134. Mr. Frank C. Allen of OCD's Directorate of Research was the project monitor. These tests are reported under Stanford Research Institute Subcontract No. B-64220(4949A-16)-US. Mr. C. A. Grubb of SRI is the project monitor. The contracts provided for forced ventilation tests of representative identified fallout shelters: (a) to evaluate parameters that determine the nature of the resultant environment in identified shelters in existing buildings, (b) to determine minimum equipment requirements for control of the environment in accordance with limiting criteria, and (c) to obtain and correlate experimental data in support of current or modified computational methods or for direct use as empirical data.

Experimental and analytical work regarding natural ventilation tests of fallout shelters has begun under the SRI contract. Such tests have already been performed in Baton Rouge, Louisiana, and Bozeman, Montana. A final report of all natural ventilation tests will be available upon completion of all tests.

## ABSTRACT

The results of two years' field testing of fallout shelters is reported herein. Simulated occupants (Simocs) and forced flow conditioned air were used to duplicate emergency environmental conditions. Nine tests have previously been documented in detailed Interim Reports. Based on field measurements of temperature, humidity and heat flux, and supplemented by an analytical computer program, an "adiabatic" procedure is recommended to predict shelter environmental conditions. This adiabatic procedure neglects heat transmission through the shelter boundary surfaces and can predict shelter effective temperatures to within 2°F. The procedure is conservative in that it will over-estimate the shelter temperature for all shelters tested.

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## SECTION 1

## INTRODUCTION

During the period from October 1962 to September 1964, forced ventilation tests were performed by GARD on nine fallout shelters. A brief summary of these tests is presented in Table 1. All tests have been previously described in detailed Interim Reports (Ref. 1A to 1H and 2) and these should be referred to for specific details. The principle objective of the test series is to determine the minimum equipment requirements (ventilation rates) for maintaining habitable conditions of temperature and humidity within building types which may serve as possible fallout shelters. A secondary objective is to obtain experimental data to be used to verify analytical methods of predicting shelter psychrometric conditions resulting from ventilation with ambient air.

Sufficient combinations of shelter geographic locations, types, configurations and sizes were tested to assure a thorough study of the parameters affecting fallout shelter environment. The shelters were tested with various occupancy, lighting and equipment loads, ventilation rates, and in some cases different air distribution systems were evaluated. Since critical shelter conditions will occur during hot and/or humid weather, all tests except one were conducted during periods of warm weather. If possible, the tests were performed when ambient conditions approached summer design weather, or these conditions were simulated and sufficient data obtained to correct nondesign test results to design conditions.

Table 1

Summary of Forced Ventilation Tests

| Test Location | Type of Shelter | Type of Forced Ventilation Test(s) | Test Date | Total Occupancy |
|---|---|---|---|---|
| Houston, Texas | Partially Belowground | a) Programmed cycle test using average hourly conditions for a typical August in Houston, Texas; (various cfm and occupancy levels)<br>b) Constant 75°F DBT and 95-100% RH Test<br>c) "No Ventilation" test | 10 Oct<br>2 Nov<br>1962 | 400 |
| Chicago, Illinois | Aboveground | a) Ambient air tests @ 3 and 2 cfm/occupant<br>b) "No Ventilation" test | 18-29<br>March<br>1963 | 330 |
| Milwaukee, Wisc. | Aboveground | a) Ambient air tests at various cfm using different air distribution systems<br>b) Controlled supply air test; constant dew-point and ambient dry-bulb temperatures<br>c) Dehumidified air tests simulating a refrigerated coil and well water coil systems. | 30 June<br>25 Jul<br>1963 | 240 |
| Milwaukee, Wis. | Partially Belowground | a) Programmed cycle test using (5%) Milwaukee summer design cycle (various cfm)<br>b) Constant inlet air condition test (ave. of 5% Milwaukee design)<br>c) Simulated air conditioned shelter test.<br>d) Constant inlet air condition test (hot and humid climate) | 11-31<br>August<br>1963 | 200 |
| Wilmington, N.C. | Aboveground | a) Ambient air test: @ 5, 9, and 15 cfm/occ.<br>b) Programmed cycle tests at various cfm using summer design cycles of Wilmington, N.C. (2-1/2%), Phoenix, Arizona (5%), and Milwaukee, Wisconsin (2-1/2 - 5%) | 9-28<br>Oct<br>1963 | 200 |
| Wilmington, N.C. | Belowground | a) Programmed cycle test using (5%) Wilmington, N.C. summer design cycle (various cfm)<br>b) Constant dehumidified air test<br>c) "No Ventilation" test | 5-13<br>Nov<br>1963 | 300 |
| Bozeman, Montana | Aboveground | Ambient Air Tests:<br>1) 460 occ. @ 3, 5, and 7 cfm/occ.<br>2) 275 occ. @ 3, 7, and 11 cfm/occ. | 11-29<br>June<br>1964 | 275,<br>460 |
| Athens, Georgia | Belowground | Human Occupancy Tests (evaluation of various air distribution systems) | 31 July<br>2 Aug<br>1964 | 300 |
| Providence, R.I. | Partially Belowground | 14-Day Ambient Air Test @ 8.5 cfm/occ. | 23-Aug<br>6 Sept<br>1964 | 500 |

For each test extensive data were recorded on shelter, inlet and ambient air conditions, as well as heat flux and temperature distributions in the shelter surfaces and in the surrounding soil of belowground shelters.

## 1.1 Simulated Occupancy

For all tests in this series (except one), the metabolic load of the shelter occupants was simulated by aggregate Simocs (Fig. 1) (Ref. 3). Each of these electromechanical devices can simulate the latent and sensible energy output of up to sixty sedentary human beings (400 Btu per hr-occupant). The electrical energy supplied to the Simoc heaters represented the total metabolic load and was manually adjusted by means of a variable transformer on each Simoc. The moisture output of the shelter occupants was provided by a humidifier located in each Simoc. As the shelter dry-bulb temperature varied, the rate at which water was atomized into the shelter was automatically controlled to match the human output.

## 1.2 Instrumentation

### 1.2.1 Air Flow

For most of the tests in this series, pre-conditioned or untempered ambient air was supplied to the shelter by means of a 24-inch diameter flexible duct, a sheet metal air metering station and an appropriate length of polyethylene duct. The plastic duct was either placed on the shelter floor or hung from the ceiling and ventilation air delivered to the shelter from one or more openings in the plastic duct.

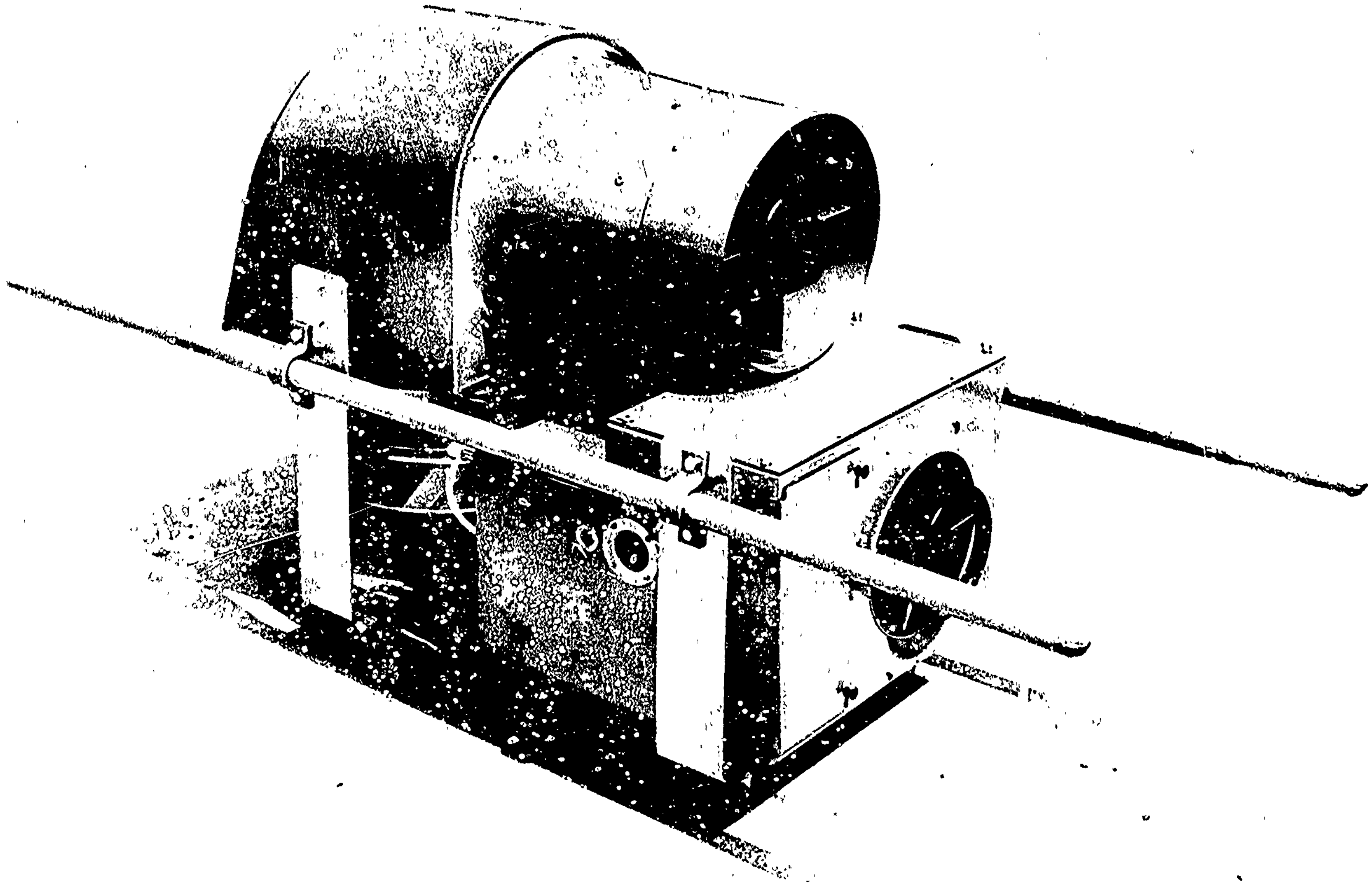

Fig. 1 AGGREGATE SIMULATED OCCUPANT (SIMOC)

A reasonably accurate measurement of the shelter ventilation rate was obtained from air velocity measurements at the air metering station with either a thermal anemometer (Alnor Model No. 8500), propeller-type anemometer (Gill Model B) or a hand-held rotating vane anemometer (Taylor Biram's Type No. 3132). The accuracy of all anemometers is estimated at ± 5 per cent.

1.2.2 Temperature Measurement

Shelter, inlet and ambient wet- and dry-bulb temperatures were measured with aspirating psychrometers (Sargent No. S 42610) equipped with copper-constantan thermocouple sensors. In some instances, the wet-bulb thermocouples were replaced by mercury bulb thermometers graduated at 1/2°F intervals to obtain more accurate data. For portable indication of psychrometric conditions, the Bendix Model 566-2 "Psychron" mercury bulb psychrometer was used. The Minneapolis-Honeywell "Dewprobe" (Model SSP129B) was used to directly measure the dew point of the shelter air. However, because this sensor required careful handling and frequent maintenance to maintain calibration, its use was discontinued after the first few shelter tests.

Additional dry-bulb temperatures were obtained from resistance bulb thermometers and copper-constantan thermocouples located inside and outside the shelter. Temperature measurements employing thermocouples included wall, floor, ceiling and partition surface temperatures; wall interior temperatures and surrounding soil temperatures. All thermocouple measurements were recorded by strip-chart multi-point recorders. Glass thermometers and resistance bulbs are accurate to ± 1/2°F; thermocouples are accurate to ± 1°F.

### 1.2.3 Heat Transmission

Heat transmission measurements through shelter surfaces were made at the inside surface of the geometric center of each major surface of the shelter. The heat flux transducers (National Instrument Laboratories Model HF-3) consisted of a disk with a spiral thermopile moulded in a filler material of polyvinyl-chloride. These were held in contact with the shelter surfaces by means of an aluminum plate fastened to the surface by nylon screws or were simply taped to the surface with a sufficient amount of heat conducting compound spread between meter and surface to assure a good thermal contact. A third installation method was to chisel away a portion of the surface material, position a heat meter in the recess and plaster over flush with the surface. The heat transmission data were recorded with a multipoint recorder. Accuracy of the heat meters, which were frequently recalibrated, is ± 5 per cent.

### 1.2.4 Shelter Energy Inputs

A kilowatt-hour meter measured the total energy input to the Simocs. Instantaneous power levels were also obtained with a precision (1%) ammeter (with current transformers) and a voltmeter. An Amprobe Model AVIX recording voltmeter and a Model AA2 recording ammeter provided a record of any voltage and current fluctuations.

Total water input to the shelter from the Simocs was measured on a balanced beam platform scale, with an estimated accuracy of ± 1/2 pound.

## 1.3 Test Vehicle

The air supply for the shelter tests was obtained from the OCD Test Vehicle No. 1 (Fig. 2) (Ref. 4). The test vehicle is capable of supplying up

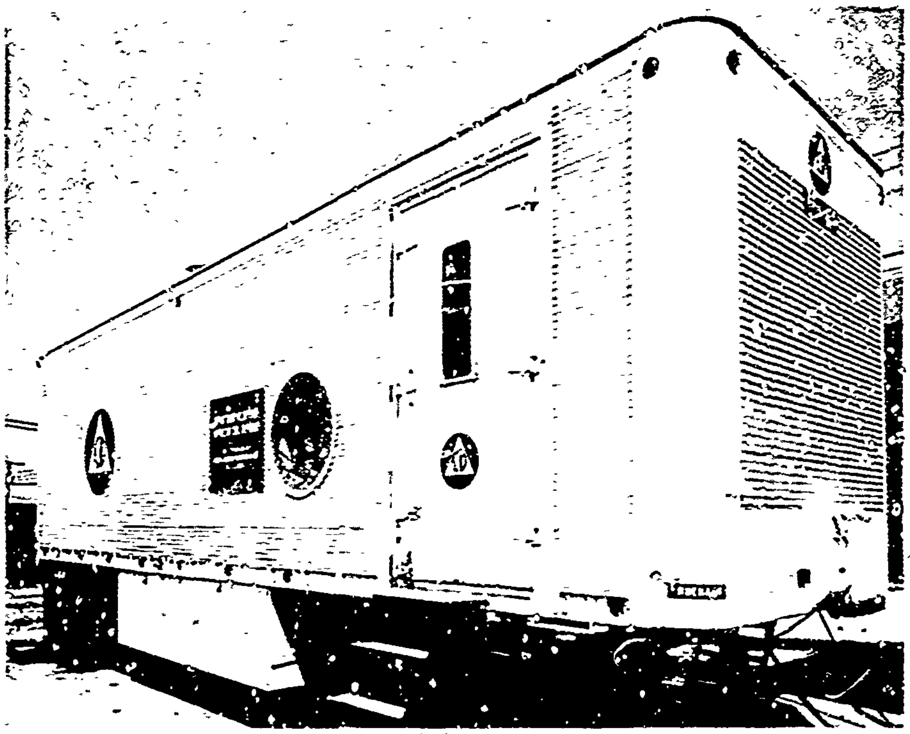

Fig. 2 OCD TEST VEHICLE NO. ONE

to 6600 cfm of air at a predetermined constant dew point temperature and a dry-bulb temperature which may be automatically cycled as a function of the time of day. The dry-bulb temperature was controlled by reheating the supply air with a hot water coil. Dehumidification was accomplished by a 20 ton water chiller, and humidification (and reheat) was achieved by a hot water boiler with a gross output of 800,000 Btu per hour. The air flow was manually controlled by adjusting the fan speed, the fan inlet vanes, and the air by-pass ports.

## SECTION 2

## TEST RESULTS

Individual test descriptions and significant results are summarized in this section, arranged in the chronological order of the performance of the tests.

### 2.1 Houston Basement Test

Forced ventilation tests were conducted in Houston, Texas (Ref. 1A) during October of 1962 in a partially belowground shelter area. High earth temperatures and weather equivalent to that occurring in summer provided ambient conditions which result in maximum ventilation requirements and very small heat transmission losses for this location. Test results indicated that with average August weather prevailing, a minimum ventilation rate of 13 cfm per occupant is required to keep the shelter effective temperature from exceeding 85°F. With simulated well water cooled inlet air (constant 75°F dry-bulb temperature and 95-100 per cent relative humidity), a minimum ventilation rate of 9 cfm per occupant would be needed.

Heat balance calculations made from heat meter data sometimes showed unbalances, i.e., the sum of the heat transmission loss and the heat loss to the exhaust air was often less than the total heat input to the shelter. This discrepancy resulted from erroneous measurements by the heat flow transducers, and consequently, no accurate analysis regarding heat dissipation and transfer rates through the shelter boundaries and surrounding soil could be made (overall shelter heat transmission could be estimated indirectly). Table 2 presents a tabulation of shelter boundary surface construction features.

Table 2

Houston Shelter Boundary Surface Properties

| Surface | Interior or Exterior | Construction | Area ($ft^2$) | Weight ($lb/ft^2$) | U * ($Btu/hr-ft^2-°F$) |
|---|---|---|---|---|---|
| EAST, WEST and NORTH Belowgrade walls | Ext | 12" concrete | 1454 | 140 | 0.61 |
| EAST and NORTH above-grade walls | Ext | 12" concrete | 230 | 140 | 0.53 |
| SOUTH wall | Int | 2" x 4" studs with 1/2" Celotex board and nominal 3" aluminum foiled fiber-glass insulation | 643 | - | 0.07 |
| Ceiling | Int | 8" concrete | 3867 | 93 | 0.52 |
| Floor | Ext | 6" concrete | 3867 | 70 | 0.71 |

*U (overall heat transfer coefficient) calculated from ASHRAE Guide data.

2.2 Chicago Aboveground Test

Ambient air forced ventilation tests were conducted in an aboveground fallout shelter located in Chicago, Illinois (Ref. 1B) during a period of mild winter weather in March of 1963. Shelter boundary surface properties are summarized in Table 3. The shelter was tested at ventilation rates of 3, 2, and zero cfm per occupant. These tests indicate that a minimum ventilation rate of 3 cfm per occupant was more than adequate to meet thermal environmental requirements while the 2 cfm per occupant ventilation rate was found to be inadequate in limiting the maximum shelter effective temperature to below 85°F. During the 3 cfm per occupant test (4 days) the shelter dry-bulb temperature range was 82°F to 74°F and the effective temperature range was 76°F to 68°F with an average effective temperature of 73°F. Average effective temperatures for the 2 cfm per occupant (3-1/2 days) and the zero ventilation (3 days) tests were 85°F and 86°F, respectively. During the latter two tests, condensation occurred on all surfaces of the shelter.

Heat meter measurements showed that approximately 50 per cent of the total input energy was lost through the shelter boundary surfaces, which significantly reduced the ventilation rate requirements. However, in critical summer weather with higher ambient temperatures, any surface heat transmission would be considerably smaller, and ventilation requirements nearer the adiabatic* rate would be necessary. Although adjacent shelter spaces were heated to the same

*Adiabatic refers to a simplified shelter model which neglects any heat transmission through the shelter boundary surfaces and assumes all metabolic and internally generated energy is removed by the ventilating air (Ref. 5).

Table 3

Chicago Shelter Boundary Surface Properties

| Surface | Surface* Construction | Area ($ft^2$) | Weight ($lb/ft^2$) | U ** ($Btu/hr\text{-}ft^2\text{-}°F$) |
|---|---|---|---|---|
| Ceiling | 6" reinforced concrete | 3344 | 70 | 0.59 |
| Floor | 6" reinforced concrete | 3344 | 70 | 0.43 |
| NORTH wall | 13" common brick | 745 | 130 | 0.29 |
| SOUTH wall | 13" common brick | 741 | 130 | 0.29 |
| WEST wall | 13" common brick | 429 | 130 | 0.29 |
| EAST wall | 18" common brick | 429 | 180 | 0.22 |
| | | Total 9028 | | |

* window area insignificant

** U (overall heat transfer coefficient) calculated from data in ASHRAE Guide.

dry-bulb temperature as the shelter, about 40-60 per cent of the total heat transfer was through adjacent area surfaces (floor and ceiling). This indicates that in winter an internal surface cannot be assumed to be adiabatic even if the temperature differential across it is reduced to small proportions. This effect is probably due to slab edge heat losses

Air infiltration tests illustrated the effect of wind velocities and surface quality on infiltration rates. For this shelter (32,000 cubic feet), with average wind velocities of 22 and 12 mph, the infiltration through the walls amounted to 0.10 and 0.08 air changes per hour (54 and 42 cfm), respectively.

## 2.3 Milwaukee Aboveground Test

Ventilation tests of a 240-man aboveground fallout shelter (Ref. 10) were performed with conditioned and with ambient air supplied to the corridor-type shelter at rates varying from 3 to 15 cfm per occupant. The "H"-shaped shelter was supplied with ventilation air at either the geometric center (split-path system) or at the extreme end of the corridor (single-pass system). Better air distribution was obtained with the center supply system than with the single-pass system. The ambient air test series indicated that some type of air distribution system is required for a complex aboveground shelter. The temperature distribution in the shelter showed that approximately 70 per cent of the forced ventilation air supply to the shelter exfiltrated prematurely from the shelter for both air distribution systems and did not leave the shelter at the exhaust conditions. Poor quality shelter surfaces and window fittings were responsible for this large forced exfiltration rate.

For all ambient tests the transmission losses from the shelter averaged from 15 per cent to 19 per cent of the total energy input (cool summer weather prevailing). Due to the non-uniformity of temperature within the shelter resulting from the corridor layout, variations in wall, floor and ceiling construction, and irregularities of wall surfaces caused by large windows, door and stairwell openings, a meaningful analysis could not be obtained from any heat meter data.

A summary of significant test parameters and results are presented in Table 4.

2.4 Milwaukee Basement Test

Forced ventilation tests performed on a partially-belowground fallout shelter in Milwaukee, Wisconsin (Ref. 10) during August of 1963 indicated that 6 cfm per occupant of ambient ventilating air would be necessary on a Milwaukee 5 per cent summer design day* to maintain this shelter at 85°F effective temperature. When ventilated with hot, moderately humid air, a ventilation rate of 13 cfm per occupant was needed to limit the shelter to these same design conditions. No significant differences in resultant average shelter conditions were noted when the shelter was ventilated with cyclic or constant (average of cyclic) inlet air conditions. Tables 5 and 6 tabulate significant test parameters and results, and give descriptions of shelter boundary surface.

The energy lost to the below-grade soil backed shelter during the

*Five per cent summer design day refers to the wet and dry-bulb temperatures, assumed coincident, which would be exceeded during only five per cent of the total summer hours (Ref. 6).

Table 4

Milwaukee Aboveground Tests - Significant Results

| Test and Day | cfm/occ. | Average Shelter DBT (°F) | Shelter Daily Δ DBT (°F) | Shelter Daily Δ ET (°F) | Inlet Daily Δ DBT (°F) | Inlet Daily Δ ET (°F) | Ambient Daily Δ DBT (°F) | Shelter Minus Ambient Δ DBT (°F) |
|---|---|---|---|---|---|---|---|---|
| 1-1 | 15.5 | 86.6 | 5.2 | 3.7 | 22.8 | 11.5 | 22.8 | 5.6 |
| 1-2 | 16.1 | 88.2 | 2.8 | 4.9 | 17.0 | 10.1 | 17.0 | 6.0 |
| 2-1 | 13.6 | 86.3 | 2.2 | 1.9 | 15.5 | 9.5 | 15.5 | 7.1 |
| 3-1 | 8.1 | 86.7 | 4.2 | 5.8 | 25.5 | 18.0 | 25.5 | 23.6 |
| 3-2 | 8.0 | 83.8 | 1.8 | 2.5 | 15.9 | 11.3 | 15.9 | 18.0 |
| 4-1 | 8.1 | 85.5 | 3.0 | 2.7 | 16.7 | 10.9 | 16.7 | 14.5 |
| 4-2 | 7.6 | 82.4 | 2.3 | 1.8 | 14.0 | 10.1 | 14.0 | 18.9 |
| 5-1 | 3.0 | 85.5 | 2.4 | 4.0 | 13.7 | 10.2 | 13.7 | 16.5 |
| 5-2 | 3.2 | 85.7 | 1.9 | 3.1 | 9.3 | 8.1 | 9.3 | 18.4 |
| 11-1 | 14.2 | 84.3 | 5.0 | 3.2 | 14.5 | 8.6 | 15.0 | 5.4 |
| 11-2 | 13.9 | 85.4 | 5.3 | 3.2 | 13.7 | 7.8 | 12.2 | 5.6 |
| 12-1 | 8.8 | 84.2 | 3.5 | 2.3 | 10.1 | 6.4 | 8.0 | 12.0 |
| 12-2 | 9.3 | 84.2 | 4.6 | 2.9 | 11.7 | 7.2 | 13.8 | 10.1 |
| 13-1 | 4.6 | 87.3 | 5.5 | 3.8 | 20.0 | 12.2 | 21.0 | 11.4 |
| 13-2 | 4.9 | 85.5 | 4.4 | 3.7 | 8.3 | 5.4 | 9.5 | 11.8 |
| 21-1 | 14.3 | 75.0 | 2.8 | 2.1 | 4.5 | 3.5 | 13.7 | 2.0 |
| 21-2 | 14.4 | 74.3 | 2.8 | 2.0 | 5.0 | 3.9 | 22.5 | 0.4 |
| 21-3 | 14.8 | 73.8 | 2.9 | 2.1 | 4.2 | 3.4 | 13.0 | 2.8 |
| 22-1 | 14.2 | 80.8 | 3.7 | 3.2 | 3.4 | 2.3 | 12.8 | 4.2 |

Tests 1, 2, 3, 4 and 5 - ventilated with ambient air
Tests 11, 12 and 13 - ventilated with air at ambient dry bulb temperature and constant 68°F dew point temperature
Test 21 - inlet air conditions simulated refrigeration system
Test 22 - inlet air conditions simulated well-water coil system

Table 5

Milwaukee Basement Tests - Significant Results

| Test Day | cfm/ occupant | Shelter Daily $\Delta$ DBT (°F) | Shelter Daily $\Delta$ ET (°F) | Inlet Daily $\Delta$ DBT (°F) | Inlet Daily $\Delta$ ET (°F) | Ambient Daily $\Delta$ DBT (°F) | Shelter Minus Ambient $\Delta$ DBT (°F) |
|---|---|---|---|---|---|---|---|
| 45 | 8.0 | 6.7 | 3.2 | 13.5 | 7.7 | 11.5 | 10.0 |
| 46 | 8.0 | 3.9 | 3.8 | 12.8 | 9.6 | 9.7 | 11.0 |
| 47 | 8.0 | 2.8 | 1.3 | 13.3 | 8.3 | 12.8 | 18.2 |
| 48 | 12.0 | 4.0 | 2.8 | 12.5 | 7.6 | 14.7 | 22.1 |
| 49 | 12.0 | 4.7 | 2.9 | 13.1 | 8.3 | 15.9 | 18.7 |
| 50-51 | 3.0 | 1.1 | 1.7 | 12.4 | 7.6 | 14.9 | 19.4 |
| *51 | 5.0 | -- | -- | 7.1 | 5.6 | 9.8 | 24.3 |
| 52 | 5.0 | 2.6 | 1.3 | 8.1 | 5.4 | 19.2 | 24.3 |
| 53&54 | 10.1 | 1.0 | 1.5 | 4.0 | 1.0 | 13.3 | 18.7 |
| 54&55** | 10.0 | 1.0 | 0.5 | 0.5 | 0.7 | 17.9 | 10.7 |
| *55 ** | 6.0 | 0.5 | 1.1 | 0.8 | 1.6 | 6.4 | 11.9 |
| 56 ** | 6.0 | 1.7 | 1.4 | 1.5 | 2.3 | 16.0 | 12.2 |
| 57 ** | 6.0 | 1.3 | 1.4 | 0.2 | 1.1 | 16.7 | 14.7 |
| *58 ** | 6.0 | 1.6 | 0.8 | 0.3 | 0.4 | 5.0 | 23.7 |
| 58&59** | 10.0 | 1.7 | 1.1 | 0.2 | 1.3 | 7.1 | 20.3 |
| 59&60** | 15.0 | 0.8 | 0.8 | 1.0 | 2.0 | 15.3 | 25.2 |
| 61 ** | 8.0 | 1.4 | 0.8 | 0.5 | 1.4 | 13.5 | 23.2 |
| 62&63** | 21.0 | 1.3 | 0.7 | 1.2 | 0.9 | 9.7 | 21.4 |
| *63 ** | 21.0 | 0.1 | 0.0 | 0.1 | 0.2 | 4.0 | 26.8 |

*logsheets do not cover 24-hr period

**constant inlet air conditions

Table 6

Milwaukee Basement Shelter Surface Properties

| Surface | Surface Construction | Interior or Exterior Surface | Area ($ft^2$) | Weight ($lb/ft^2$) | $U_{(exp)}$ ($Btu/hr$-$ft^2$-°F) | U* ($Btu/hr$-$ft^2$-°F) |
|---|---|---|---|---|---|---|
| Ceiling | below first floor hallway: 1/8" tile + 5-1/2" concrete slab + 6" x 12" clay tile + 1/2" plaster | Interior | 2100 | 67 | 0.32 | 0.33 |
| | rest of shelter: wood floor on sleepers + 3" cinder fill + 5" concrete slab + 1/2" plaster | | | 87 | | |
| Floor | 1/8" tile + 8" concrete slab | Exterior below-ground | 2100 | 82 | 0.19 | 0.63 |
| South wall belowgrade | 12" limestone front + 9" common brick backing | Exterior below-grade | 373 | 240 | 0.10 | 0.29 |
| South wall abovegrade | 12" limestone front + 9" common brick backing | Exterior above-ground | 150 | 240 | 0.13 | 0.38 |
| Internal walls | 2-1/2" plaster on metal lath | Interior | 1307 | 25 | 0.18 | 0.33 |
| | 9" common brick + 6" clay tile + 1/2" plaster | | | 120 | | |
| | 18" common brick + 1/2" plaster | | | 185 | | |
| | 18" common brick | | | 180 | | |

*U (overall heat transfer coefficient) calculated from data in ASHRAE Guide.

entire test was 3.9 Btu per hour-$ft^2$ or 12 per cent of the total energy input to the shelter. No significant reduction of this heat transfer was observed as the tests progressed. The wide variations in flow rates and inlet conditions tended to mask any large reduction in heat transfer which may have occurred as the temperatures of the surfaces and the surrounding soil increased. The heat transfer to soil-backed surfaces was shown to be proportional to the shelter minus earth temperature differential, and the heat transfer to "non-occupied" adjacent areas was somewhat proportional to the shelter minus ambient temperature difference. The overall heat transfer coefficient calculated from heat meter and temperature differential data was 0.23 Btu per hr-$ft^2$-°F, and is approximately one-half the overall coefficient calculated from the ASHRAE Guide of 0.43 (Ref. 6).

## 2.5 Wilmington Aboveground Test

Ventilation tests at various flow rates and inlet conditions were performed on an aboveground fallout shelter in Wilmington, North Carolina (Ref. 1E) during October of 1963 (see Table 7). (Infiltration tests were also run, but the results of the data have little significance other than to illustrate that infiltration rate is dependent on wind speed and direction.) For this shelter, a ventilation rate of approximately [illegible] cfm per occupant is required to limit its effective temperature to 85°F when ventilated with Wilmington 2-1/2 per cent summer design air. From these tests, a procedure was developed to predict shelter ventilation requirements for any aboveground shelter in any location (Ref. 5). Using this procedure and comparing the results with adiabatic rates, predicted ventilation rates assuming heat losses were 1 to 2 cfm per occupant lower than those which were computed adiabatically.

Table 7

Wilmington Aboveground Test - Significant Results

| Test Day | Average Shelter Dry Bulb Temperature (°F) | cfm/occ. | Shelter Daily Δ DBT (°F) | Shelter Daily ΔET (°F) | Inlet Daily Δ DBT (°F) | Inlet Daily Δ ET (°F) | Ambient Daily Δ DBT (°F) | Shelter Minus Ambient Δ DBT (°F) |
|---|---|---|---|---|---|---|---|---|
| 15 | 90.0 | 9.0 | 3.8 | 2.6 | 13.5 | 7.4 | 18.1 | 22.6 |
| 16 | 89.5 | 9.0 | 4.5 | 4.2 | 13.2 | 7.9 | 16.3 | 27.3 |
| 21-22 | 88.5 | 20.0 | 6.5 | 3.0 | 13.5 | 7.6 | 20.6 | 23.1 |
| 22-23 | 89.5 | 20.0 | 5.5 | 3.3 | 13.8 | 7.5 | 22.9 | 22.7 |
| 24 | 89.5 | 7.0 | 4.4 | 3.7 | 13.3 | 8.1 | 26.0 | 25.0 |
| 25 | 90.0 | 7.0 | 3.5 | 2.2 | 14.0 | 8.6 | 26.1 | 22.3 |
| 26 | 89.2 | 7.0 | 3.5 | 2.6 | 13.6 | 8.1 | 18.7 | 19.1 |
| 27 | 88.3 | 7.5 | 4.6 | 2.4 | 12.6 | 7.8 | 9.0 | 18.9 |
| 28 | 88.7 | 7.5 | 4.3 | 3.1 | 13.1 | 8.2 | 12.0 | 17.8 |
| 30 | 89.0 | 8.5 | 5.6 | 3.2 | 14.0 | 8.7 | 11.8 | 19.4 |
| 31 | 88.8 | 8.5 | 5.9 | 3.5 | 13.8 | 8.8 | 8.8 | 20.3 |
| 33 | 94.5 | 13.0 | 11.5 | 5.9 | 28.8 | 14.1 | 13.5 | 24.5 |
| 34 | 94.9 | 13.0 | 11.4 | 6.3 | 28.0 | 13.7 | 19.5 | 24.9 |

NOTE: logsheets 15-23 Wilmington 2-1/2 per cent summer design conditions
logsheets 24-31 Milwaukee 2-1/2 - 5 per cent summer design conditions
logsheets 33-34 Phoenix 5 per cent summer design conditions

Heat fluxes through exterior surfaces (4.9 Btu per hr-ft$^2$) were over twice as large as those through interior surfaces (2.4 Btu per hr-ft$^2$) due to the greater temperature differential across the exterior surfaces. However, only 8 per cent of the total input energy to the shelter was transferred through exterior surfaces whereas the larger interior surfaces transferred approximately twice as much total energy. Under design conditions, when adjacent interior areas would be occupied, the only energy transmitted through the shelter boundary surfaces would be transferred to the external surfaces resulting in an insignificant reduction in required ventilation rate. Consequently, for this and similar shelters the adiabatic ventilation rate is recommended.

The experimental average heat transfer coefficient for exterior surfaces of 0.44 Btu per hr-ft$^2$-°F agreed very well with the ASHRAE Guide (Ref. 6) value of 0.45. The experimental coefficient for the entire shelter of 0.17, however, was somewhat less than that given by the ASHRAE Guide 0.25. This deviation is probably caused by the fact that the experimental value is based upon the shelter minus ambient temperature differential instead of an area-weighted average temperature difference. The latter could not be calculated because the temperatures of all adjacent area spaces were not measured. Table 8 presents a tabulation of shelter boundary surface construction features.

## 2.6 Wilmington Belowground Test

Forced ventilation tests were performed on a belowground fallout shelter in Wilmington, North Carolina (Ref. 11) using simulated occupants. Table 9 presents a summary of tests performed. For a Wilmington 5 per cent summer

Table 8

Wilmington Aboveground Shelter Surface Properties

| Surface | Interior or Exterior | Construction | Area ($ft^2$) | | | Weight ($lb/ft^2$) | | U* ($Btu\text{-}hr\text{-}ft^2\text{-}°F$) |
|---|---|---|---|---|---|---|---|---|
| | | | Glass | Non-Glass | Total | Glass | Non-Glass | |
| NORTH Wall | Ext. | 4" face brick + 12" common brick + 5/8" plaster | 109 | 393 | 502 | 1 | 170 | 0.45 |
| EAST Wall | Ext. | same as North wall | 135 | 525 | 660 | 1 | 170 | 0.44 |
| WEST Wall | Ext. | same as North wall | 160 | 500 | 660 | 1 | 170 | 0.47 |
| SOUTH Wall | Int. | 4" hollow clay tile + 5/8" plaster on both sides | 0 | 504 | 504 | - | 28 | 0.37 |
| Ceiling | Int. | 6" hollow clay tile + 2" concrete with 5/8" plaster and acoustical tile below, and wood and floor tile above | 0 | 3012 | 3012 | - | 64 | 0.18 |
| Floor | Int. | same as ceiling | 0 | 3012 | 3012 | - | 64 | 0.18 |

*U (overall heat transfer coefficient) calculated from data in ASHRAE Guide.

Table 9

Wilmington Belowground Test - Significant Results

| Test No. | Shelter Dry Bulb Temperature (°F) | cfm/occ. | Shelter Daily $\Delta$ DBT (°F) | Shelter Daily $\Delta$ET (°F) | Inlet Daily $\Delta$ DBT (°F) | Inlet Daily $\Delta$ET (°F) | Ambient Daily $\Delta$ DBT (°F) | Shelter Minus Ambient $\Delta$ DBT (°F) | Average Soil Temperature (°F) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 86.4 | 20.3 | 5.8 | 3.4 | 13.5 | 7.5 | 15.1 | 20.8 | 70.9 |
| 2 | 89.4 | 10.0 | 3.0 | 1.5 | 13.6 | 7.0 | 6.3 | 25.9 | 72.3 |
| 3 | 89.1 | 11.6 | 3.3 | 1.5 | 13.5 | 7.1 | 9.4 | 26.6 | 73.5 |
| 4 | 88.7 | 14.3 | 4.0 | 2.7 | 13.9 | 8.5 | 17.2 | 29.3 | 74.5 |
| 5 | 88.3 | 16.0 | 5.0 | 2.4 | 14.0 | 7.4 | 13.6 | 27.3 | 75.5 |

design day, a ventilation rate of 16 cfm of ambient air per occupant was found to be adequate to maintain this shelter at 85°F effective temperature. When the shelter was ventilated with dehumidified air (63°F dry-bulb and 59°F wet-bulb temperatures), 5 cfm per occupant was sufficient. When the ventilation was stopped completely, the shelter effective temperature increased from 85°F to 90°F in one hour, to 92°F in two hours and to 93°F in three hours. The earth temperatures during the first six days of testing increased approximately 5 to 6°F. This temperature rise resulted in a slight decrease in heat transmission losses through belowground shelter surfaces, which over the entire test period ranged from 1.6 to 6.9 Btu per hr-ft$^2$ and averaged 3.7 Btu per hr-ft$^2$. The latter value agreed fairly well with the heat loss through these surfaces predicted by procedures in the ASHRAE Guide of 4.5.

It was noted that this heat flow consistently peaked between 1200 and 1900 hours, and was a minimum between midnight and 0500 hours. Heat losses through adjacent interior surfaces was slightly less than the losses through soil-backed surfaces but may be absent in emergency situations. Heat transferred from the shelter to the surrounding soil was 14.5 per cent of the total energy input to the shelter and significantly reduced the required ventilation rate. The overall heat transfer coefficient calculated from heat meter data, an area-weighted average $\Delta$T, and the total area of the shelter was 0.43 Btu per hr-ft-°F, which is less than the U value of 0.56 determined from the ASHRAE Guide. Table 10 lists shelter surface properties.

Table 10

Wilmington Belowground Shelter Surface Properties

| Surface | Construction | Area ($ft^2$) | Weight ($lb/ft^2$) | U* ($Btu/hr-ft^2-°F$) |
|---|---|---|---|---|
| NORTH Wall | 10" poured concrete | 713 | 117 | 0.67 |
| EAST Wall | 10" poured concrete | 534 | 117 | 0.67 |
| SOUTH Wall | 22" poured concrete to 9' height, then 2' brick | 713 | concrete portion 257<br>brick portion 220 | 0.41<br>0.20 |
| Floor | 4" concrete slab | 3100 | 47 | 0.81 |
| Ceiling | 2" poured concrete over 6" hollow clay tile with asphalt tile on floor above | 3100 | 74 | 0.34 |
| WEST Partition | 2" x 4" studs on 16" centers with 1/2" plasterboard on outside | 534 | 3 | 0.55 |

*U (overall heat transfer coefficient) computed from data in ASHRAE Guide.

## 2.7 Bozeman Aboveground Test

An eighteen-day, 400-man simulated occupancy test was performed on a second floor fallout shelter in Bozeman, Montana Ref. 10, during June of 1964. The shelter was ventilated with outside air at flow rates from 3 to 11 cfm per occupant. The energy loss through the shelter boundary surfaces amounted to 17.4 per cent of the total energy input to the shelter. The energy loss through the interior surfaces (11.9 per cent) was twice as large as the exterior surface loss (5.5 per cent). For the average June day, which approximated actual test weather, the shelter when loaded with one occupant per ten square feet of floor area, would require 4.5 cfm per occupant to limit the shelter average effective temperature to 85°F. This is an 18 per cent reduction from the adiabatic rate of 5.5 cfm per occupant. For the hottest June day on record, the shelter would require 7.0 cfm per occupant, a 7 per cent reduction from the adiabatic rate of 7.5 cfm per occupant. The above rates are based on the assumption that the floors adjacent to the shelter were unoccupied. Under emergency conditions, this would probably not be the case. Heat transmission losses from the shelter would, therefore, be reduced, and the corresponding reduction in air flow rate would be less than 0.5 cfm per occupant. Consequently, the adiabatic model is recommended for selecting ventilation requirements for this and similar shelters.

The average heat transfer coefficient for the shelter given by the ASHRAE Guide is 0.45 Btu per hr-ft$^2$-°F. This compares favorably with the calculated experimental coefficient of 0.40, which is based on an area-weighted overall average $\Delta T$.

This test provided shelter and weather data for a companion study which mathematically predicted hourly shelter psychrometric conditions. These data included hourly weather conditions, shelter construction and configuration details, and adjacent interior area temperatures. Predicted shelter dry-bulb and effective temperatures were generally within 2°F and 1°F of the experimental shelter dry-bulb and effective temperatures, respectively, when actual adjacent interior temperatures were used in the calculations. When the temperatures of adjacent non-shelter areas were estimated, the agreement was generally within 2°F for both shelter dry-bulb and effective temperatures. It was concluded from these results that without a more accurate interior temperature estimation technique, further refinement of this analytical method would not be possible.

A summary of significant test parameters and results are presented in Table 11 Table 12 lists shelter surface construction characteristics and physical properties

## 2.8 Athens Human Occupancy Test

A fifty-hour, 300-human occupant forced ventilation test was conducted in a basement fallout shelter in Athens, Georgia (Ref. 1H) in conjunction with the University of Georgia. During the test, ventilation air was supplied to the shelter by means of three different ventilation systems. In the first portion of the test, the installed shelter ventilation system was used and found to be adequate to maintain habitable shelter conditions if the central refrigeration plant is operating. Following this, two simplified ventilation systems constructed of plastic (polyethylene) duct was evaluated. One system

Table 11

Bozeman Aboveground Test - Significant Results

| Test Day | Average Shelter Dry Bulb Temperature (°F) | cfm/occ. | Shelter Daily Δ DBT (°F) | Shelter Daily Δ ET (°F) | Inlet Daily ΔDBT (°F) | Inlet Daily Δ ET (°F) | Ambient Daily Δ ET (°F) | Shelter Minus Ambient Δ DBT (°F) |
|---|---|---|---|---|---|---|---|---|
| 3 | 86.0 | 3.4 | 3.0 | 2.0 | 17.0 | 13.0 | 25.0 | 32.0 |
| 4 | 85.0 | 3.4 | 3.0 | 3.0 | 18.0 | 14.0 | 25.0 | 28.0 |
| 5 | 84.0 | 5.6 | 4.0 | 5.0 | 16.0 | 13.0 | 23.0 | 27.0 |
| 6 | 83.5 | 5.2 | 3.0 | 3.5 | 15.0 | 12.5 | 19.5 | 28.5 |
| 7 | 84.5 | 5.0 | 2.0 | 2.0 | 10.5 | 8.0 | 13.0 | 25.5 |
| 8 | 82.5 | 6.5 | 3.0 | 4.5 | 8.5 | 7.5 | 9.0 | 31.0 |
| 9 | 82.0 | 6.8 | 3.0 | 3.0 | 15.5 | 13.0 | 16.0 | 31.0 |
| 10 | 82.0 | 6.9 | 4.0 | 3.9 | 12.0 | 9.5 | 13.5 | 32.5 |
| 11 | 86.5 | 3.0 | 4.5 | 5.5 | 12.0 | 10.0 | 18.5 | 35.5 |
| 12 | 86.5 | 2.9 | 1.0 | 1.5 | 11.5 | 10.0 | 17.5 | 35.5 |
| 13 | 84.0 | 2.8 | 2.0 | 2.0 | 13.5 | 10.5 | 24.0 | 29.0 |
| 14 | 85.0 | 3.1 | 3.5 | 3.5 | 22.0 | 15.5 | 37.0 | 22.0 |
| 15 | 83.0 | 6.9 | 6.0 | 4.5 | 22.5 | 15.0 | 33.5 | 13.5 |
| 16 | 85.0 | 7.5 | 3.5 | 2.5 | 21.0 | 14.0 | 31.0 | 16.5 |
| 17 | 84.0 | 10.8 | 4.0 | 4.0 | 22.0 | 15.0 | 31.0 | 16.0 |
| 18 | 85.0 | 10.7 | 3.5 | 2.5 | 19.0 | 11.5 | 27.0 | 14.0 |
| 19 | 86.0 | 5.7 | 5.0 | 4.0 | 18.0 | 13.5 | 24.5 | 28.0 |
| 20 | 85.5 | 4.9 | 4.0 | 3.0 | 18.0 | 13.0 | 26.0 | 24.5 |

NOTE: Test Day 3-10 and 19 and 20 = 460 occupants

Test Day 11-18 = 275 occupants

Table 12

Bozeman Aboveground Shelter Surface Properties

| Surface | Interior or Exterior | Construction | Area ($ft^2$) | Weight ($lb/ft^2$) | U* ($Btu/hr\text{-}ft^2\text{-}°F$) |
|---|---|---|---|---|---|
| Temporary Partition | Int. | 1/4" plywood + 4 mil polyethylene film + 1 foot air space + 4 mil plastic film | 1130 | 0.7 | 0.28 |
| NORTH and WEST Walls (Lightweight Portion) | Ext. | 8" concrete block + 4" face brick | 155 | 75 | 0.30 |
| NORTH and WEST Walls (Heavyweight Portion) | Ext. | 12" concrete block + 4" face brick | 595 | 86 | 0.27 |
| NORTH and WEST Walls (Glass Portion) | Ext. | 1" Thermopane | 345 | 6.5 | 0.56 |
| Stairwell and Fan Room Walls | Int. | 8" poured concrete | 870 | 93 | 0.50 |
| Ceiling | Int. | Precast concrete beam + 2" concrete slab (average thickness = 7.7") | 4555 | 82 | 0.54 |
| Floor | Int. | same as ceiling | 4555 | 82 | 0.41 |

*U (overall heat transfer coefficient) calculated from data in ASHRAE Guide

was a single-inlet arrangement in which all of the ventilation air was supplied at one end of the shelter and exhausted at the opposite end. The other arrangement was a distribution-type system, i.e., air inlet holes were cut into the plastic duct at uniformly spaced intervals The single-inlet system provided adequate air mixing with a single room, with the stipulation that the air inlet was designed to eliminate local drafts. The more conventional distribution-type of system should be used to supply air to partitioned areas, but is an unnecessary luxury in a single-room shelter. A minimum thickness of 4 mils is recommended for the plastic air duct to provide adequate resistance to damage.

## 2.9 Providence Basement Test

A 14-day ambient air test was run in a partially belowground fallout shelter in Providence, Rhode Island (Ref. 2) during August of 1964 at a constant ventilation rate of 8.5 cfm per occupant. Ventilation air was uniformly distributed in the shelter by a plastic duct at floor level. During the test, almost no temperature stratification in the shelter was evident. Surrounding soil temperatures increased as the test progressed, and the temperature rise was greater for soil nearer the wall and caused the total shelter heat loss rate to decrease slightly during the test. Transmission losses to aboveground exterior surfaces were most sensitive to changes in ambient air conditions.

Approximately 23 per cent of the total input energy to the shelter was lost through the shelter boundary surfaces. This accounted for a 30 per cent reduction from the computed adiabatic ventilation rate. Roughly one-half of this total heat transmission was conducted through aboveground

exterior boundaries and one-third through soil-backed surfaces. However, it is concluded that under design-day conditions, the most important heat sink would be the soil-backed exterior surfaces. The heat flux through these surfaces was smaller (2.7 Btu per hr-ft$^2$-°F) than observed during previous GARD shelter tests.

The experimental overall heat transfer coefficient computed from an area-weighted average $\Delta T$ was 0.25 Btu per hr-ft$^2$-°F, which is quite different from the ASHRAE Guide value of 0.38. It is believed that this disagreement was due to transient heat transfer effects, and the inability to properly measure the temperature of the outside surface of exterior belowground surfaces. Physical properties of the shelter boundary surfaces are shown in Table 13; a summary of daily test averages is presented in Table 14.

The empirical data from this test was used in conjunction with a computer program to analytically predict shelter psychrometric conditions entirely without the knowledge of experimental shelter and adjacent interior area temperature data. Input information supplied to the computer program consisted of measured hourly inlet air wet and dry-bulb temperatures, estimated cloud cover, day of year and latitude of the shelter location. Besides this weather data, other inputs included ventilation rate, number of occupants, instrumentation load and various shelter construction and configuration details. The mathematical predictions (both dry-bulb and effective temperatures) were generally within 1.5°F of the experimental results. It was therefore concluded that this analytical method can be used to accurately predict shelter psychrometric conditions for given inlet conditions for this type of shelter.

Table 13

Providence Basement Shelter Surface Properties

| Boundary Surface | Construction | Area ($ft^2$) | Thickness (in.) | Weight ($lb/ft^2$) | U* ($Btu/hr-ft^2-°F$) |
|---|---|---|---|---|---|
| SOUTH exterior wall belowground | 36" poured concrete | 820 | 36 | 420 | 0.28 |
| SOUTH exterior wall aboveground | 20" brick + 4" marble | 1630 | 24 | 250 | 0.19 |
| EAST exterior wall belowground | 36" poured concrete | 905 | 36 | 420 | 0.28 |
| EAST exterior wall aboveground | 20" brick + 4" marble | 1795 | 24 | 250 | 0.19 |
| Floor | 4" concrete | 4690 | 4 | 46 | 0.81 |
| Ceiling | 4" brick + 11" (average) concrete + 1" marble | 4690 | 16 (average) | 181 | 0.34 |
| Interior brick wall | 30" (average) brick | 3280 | 30 (average) | 300 | 0.13 |
| Interior concrete block wall | 8" concrete block | 875 | 8 | 43 | 0.38 |
| WEST exterior wall belowground | 24" (assumed) concrete | 220 | 24 | 280 | 0.37 |

*U (overall heat transfer coefficient) calculated from data in ASHRAE Guide

Table 14

Providence Basement Test - Significant Results

| Test Day No. | Average Shelter Dry-Bulb Temperature (°F) | Shelter Daily Δ DBT (°F) | Shelter Daily Δ ET (°F) | Inlet Daily Δ DBT (°F) | Inlet Daily Δ ET (°F) | Ambient Daily Δ DBT (°F) | Ambient Daily Δ ET (°F) | Shelter Minus Ambient Δ DBT (°F) |
|---|---|---|---|---|---|---|---|---|
| 1 | 81.5 | 5.0 | 4.5 | 6.5 | 7.5 | 8.5 | 8.0 | 17.5 |
| 2 | 86.0 | 5.0 | 3.0 | 16.5 | 11.0 | 20.5 | 15.0 | 11.5 |
| 3 | 87.0 | 1.0 | 3.0 | 9.5 | 6.0 | 13.0 | 8.0 | 12.0 |
| 4 | 86.0 | 4.5 | 6.0 | 16.0 | 14.5 | 19.5 | 17.0 | 18.5 |
| 5 | 85.5 | 3.0 | 2.0 | 17.0 | 10.5 | 21.0 | 16.0 | 15.5 |
| 6 | 85.5 | 2.0 | 1.5 | 11.0 | 6.0 | 13.0 | 9.0 | 16.5 |
| 7 | 87.5 | 2.5 | 3.5 | 12.0 | 10.0 | 13.5 | 11.0 | 13.5 |
| 8 | 89.5 | 1.5 | 2.5 | 12.0 | 8.0 | 14.5 | 9.5 | 11.0 |
| 9 | 89.5 | 3.0 | 3.5 | 10.5 | 9.0 | 11.5 | 10.0 | 11.5 |
| 10 | 87.5 | 4.5 | 4.5 | 21.5 | 15.0 | 24.0 | 18.0 | 16.5 |
| 11 | 86.5 | 3.0 | 3.0 | 14.0 | 9.5 | 13.5 | 10.0 | 19.5 |
| 12 | 87.5 | 3.0 | 2.0 | 10.0 | 6.0 | 10.0 | 9.5 | 16.5 |
| 13 | 88.0 | 2.5 | 4.0 | 9.5 | 7.0 | 8.5 | 8.0 | 13.0 |
| 14 | 88.0 | 4.0 | 4.5 | 20.5 | 14.0 | 22.0 | 17.5 | 15.5 |

## SECTION 3

## SUMMARY OF RESULTS

A tabulated summary of important test results, as taken from the interim reports, is presented in Table 15. Significant results are summarized as follows:

1) During all aboveground tests, the shelter always lost energy by transmission through the boundary surfaces However, in an emergency occurred on a hot summer day, this heat loss cannot be expected to occur because: (a) the tests were conducted during a period when cooler than design summer weather prevailed, thus increasing the heat loss through the external surfaces, and/or (b) the building areas adjacent to the shelter were unoccupied (and thus cooler than the shelter area); during an emergency these areas would usually be occupied, eliminating this heat sink.

2) During most belowground tests, the shelter lost energy to concrete soil-backed surfaces, as indicated below in Table 16.

Table 16

Belowground Heat Losses

| Test | Heat Loss to Belowgrade Exterior Shelter Surfaces Btu/hr-ft$^2$ | Initial Soil Temperatures °F |
|---|---|---|
| Milwaukee Basement | 4.0 | 64 |
| Wilmington Belowground | 3 7 | 70 |
| Providence Basement | 2.7 | 73 |

Table 15

Summary of MRI Forced Ventilation Shelter Tests

| Test Location | Aboveground (AG) Belowground (BG) or Partially BG (PBG) | Average Ambient (°F) Temperature | | Average Shelter (°F) Temperature | | Soil Characteristics | Average Soil Temperature (°F) | | Condensation of Water Vapor on Shelter Surfaces | Sq. Ft. of Belowground Surface Area Per Occupant | Area-Weighted Average Shelter Surface $lb_m/ft^2$ | Average Heat Flux Through Shelter Boundary Surfaces Btu/hr-ft² | | | | Avg. % of Total Input Energy Transferred Through Shelter Boundary Surfaces | | | | Overall U | Overall U ASHRAE Guide |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | DBT | Et | DBT | ET | | Initially | After 14 Days | | | | AG Ext. | BG Ext. | Int. | Total | AG Ext. | BG Ext. | Int. | Total | | |
| Houston, Texas | PBG | 71.3 | 68.5 | 88.8 | 84.8 | Mostly Clay | ** | ** | None | 13.3 | [illegible] | ** | ** | ** | ** | ** | ** | ** | ** | ** | .5[illegible] |
| Chicago, Illinois | AG | 45.9 | ** | 84.0 | 81.1 | * | * | * | Occurred During 2 cfm/occ. Test and No Ventilation Test | * | 88 | ** | * | ** | 7.4 | ** | * | ** | 53.2 | ** | 0.45 |
| Milwaukee, Wisconsin | AG | 73.2 | 69.3 | 83.4 | 78.3 | * | * | * | None | * | 83 | ** | * | ** | 2.0 | ** | * | ** | 17.0 | ** | ** |
| Milwaukee, Wisconsin | PBG | 68.8 | 66.1 | 87.1 | 83.0 | Silt and Clay | 64.4 | ** | None | 12.4 | 97 | 2.3 | 4.0 | 3.[illegible] | 3.[illegible] | 0.4 | 11.7 | 15.0 | 27.1 | 0.23 | 0.43 |
| Wilmington, North Carolina | AG | 67.9 | 65.7 | 90.1 | 85.2 | * | * | * | None | * | 77 | 4.9 | * | 2.4 | 3.0 | 7.9 | * | 14.1 | 22.0 | .17 | .25 |
| Wilmington, North Carolina | BG | 62.4 | 54.5 | 88.4 | 85.4 | Sand and Fill Material | 70.1 | 75.7 (after six days) | None | [illegible] | 81 | * | 3.7 | 4.4 | 4.0 | * | [illegible] | 12.2 | [illegible] | 0.43 | .5[illegible] |
| Bozeman, Montana (Library) | AG | 58.3 | 56.6 | 84.4 | 80.0 | * | * | * | None | * | 73 | 5.2 | * | 1.8 | 2.3 | 5.5 | * | 11.0 | 17.4 | .40 | .45 |
| Athens, Georgia | BG | | | | | (HUMAN | OCCUPANCY | | TEST) | | | | | | | | | | | | |
| Providence, Rhode Island | PBG | 71.9 | 68.8 | 86.8 | 81.8 | Sand and Gravel | 72.8 | 78.5 | None | 13.3 | 200 | 3.1 | 2.7 | 2.1 | 2.7 | 10.8 | 7.6 | 4.2 | 22.6 | 0.25 | 0.3[illegible] |

*not applicable

**not available

The soil surrounding the Milwaukee shelter was silt and clay, while the other two shelters had a dry sand and gravel fill mixture. It is suspected (data not sufficiently accurate) that the heat loss during the Houston test approached zero, as the soil temperature exceeded 90°F As the above four tests were conducted during the summer, it is reasonable to assume that these heat losses would also exist during a summer design day emergency, since subsurface soil temperatures show little diurnal variations.

3) The shelter diurnal dry-bulb and effective temperature cycles closely follow the ambient cycles, but at diminished amplitudes. For aboveground shelters, there is a fair correlation between the ratio of the amplitudes and the air flow rates (see Figs. 3 and 4). For belowground shelters, no similar correlation could be made, since the shelter cycle is apparently a stronger function of the heat storage mass exposed to the shelter air.

4) Possibly the most significant results of this test series is the verification of the mathematical shelter model (Ref. 2). Dry-bulb and effective temperatures can almost without exception be predicted to within 2°F, usually much closer.

5) Large open shelter areas will not need elaborate conventional-type distribution systems. (Since aggregate Simocs inherently disturb the air circulation pattern within a shelter, only one test (Athens) provided an opportunity to evaluate air distribution.)

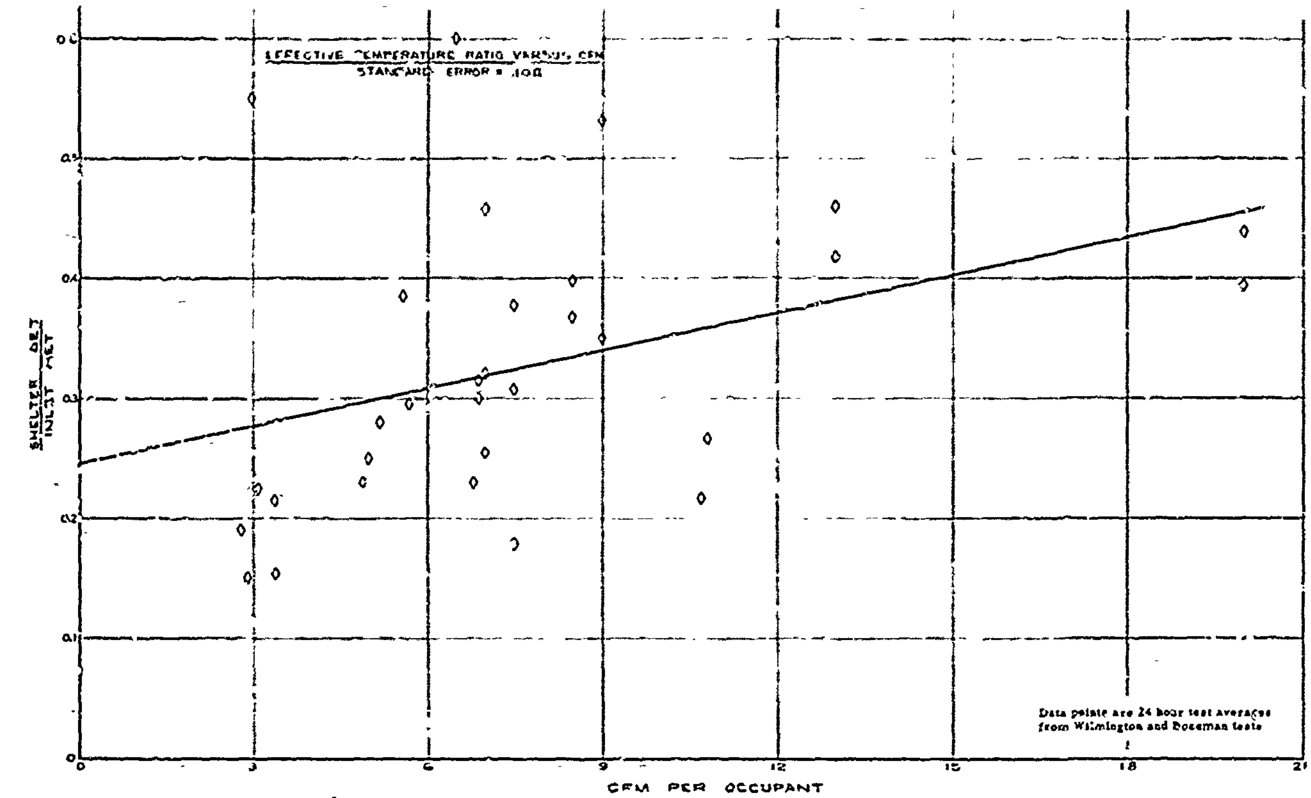


Fig. 3 ABOVEGROUND TESTS - EFFECTIVE TEMPERATURE CORRELATION

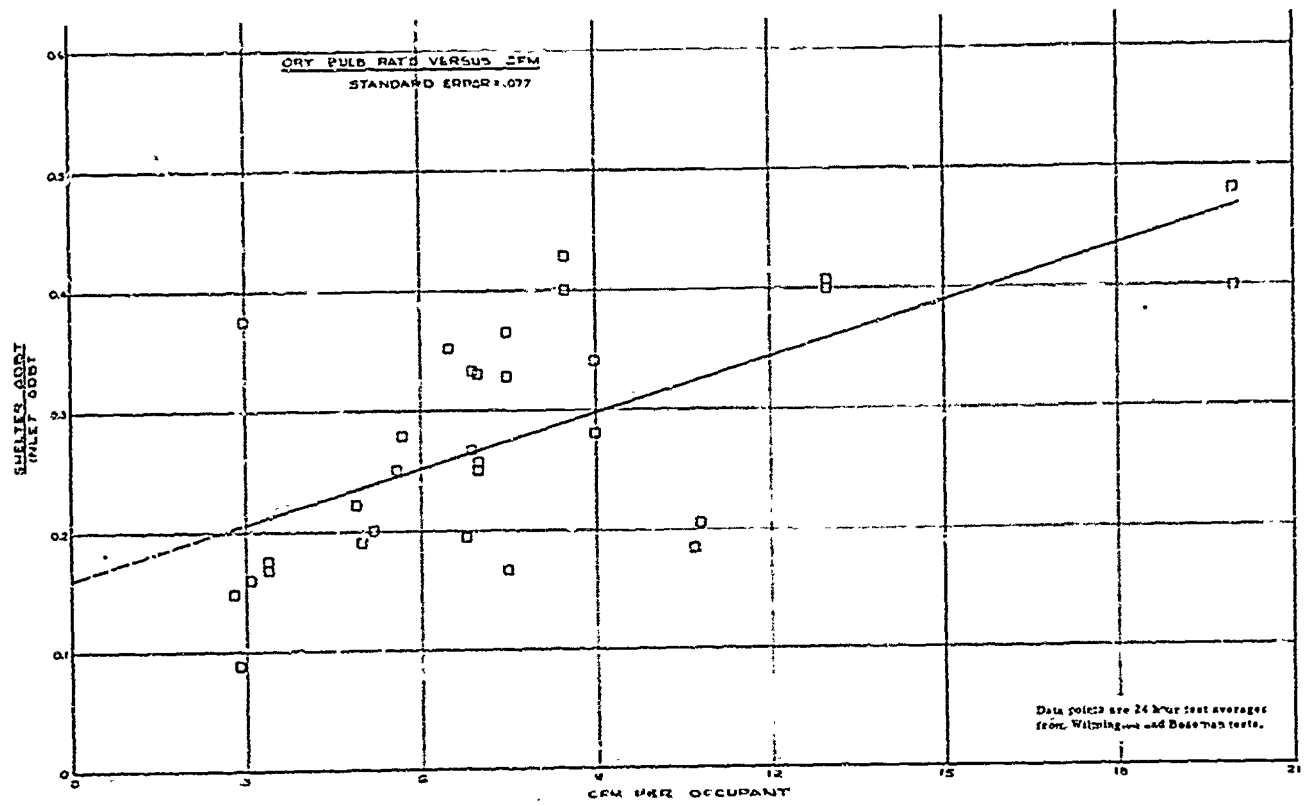


Fig. 4 ABOVEGROUND TESTS - DRY-BULB TEMPERATURE CORRELATION

## SECTION 4

## CONCLUSIONS AND RECOMMENDATIONS

The temperature and humidity that will develop in a shelter are determined by the state of heat and moisture balance at any time. The energy quanta enter or leave by the ventilating air, may be generated by metabolism or equipment in the shelter, or may be transferred by convection, conduction, radiation and condensation at the shelter boundary surfaces. A comprehensive analysis of these transient heat and moisture flows can be performed for any shelter if the extensive data are available. Computer programs ha been developed which numerically treat many aspects of this comprehensive model. The major problem in the application of these models to shelters in general, is the amount of detailed input information required to analyze any given shelter.

Only a small percentage of the total metabolism energy generated within most large shelters will be lost by heat transfer to the shelter walls during hot summer weather. This is especially true for the second week in a below-ground shelter and for every day in an aboveground shelter. Therefore, it is possible to obtain reasonable estimates of the shelter conditions developed at various ventilation rates during hot weather by neglecting the wall heat loss or gain. Reference 5 presents the details of a graphical method to make such predictions.

The results of such solutions are displayed in Figures 5, 6, and 7 for average shelter effective temperatures of 80, 82, and 85°F. These solutions are based upon the metabolic heat load of sedentary people and do not include any other

## PSYCHROMETRIC CHART FOR ESTIMATING FALLOUT SHELTER VENTILATION EFFECTS

Shelter temperature protractor based on 400 Btu per hr - occupant metabolic load only

ASHRAE PSYCHROMETRIC CHART NO. 1
NORMAL TEMPERATURE
BAROMETRIC PRESSURE 29.921 INCHES OF MERCURY
COPYRIGHT 1963
AMERICAN SOCIETY OF HEATING, REFRIGERATING AND AIR-CONDITIONING ENGINEERS, INC.

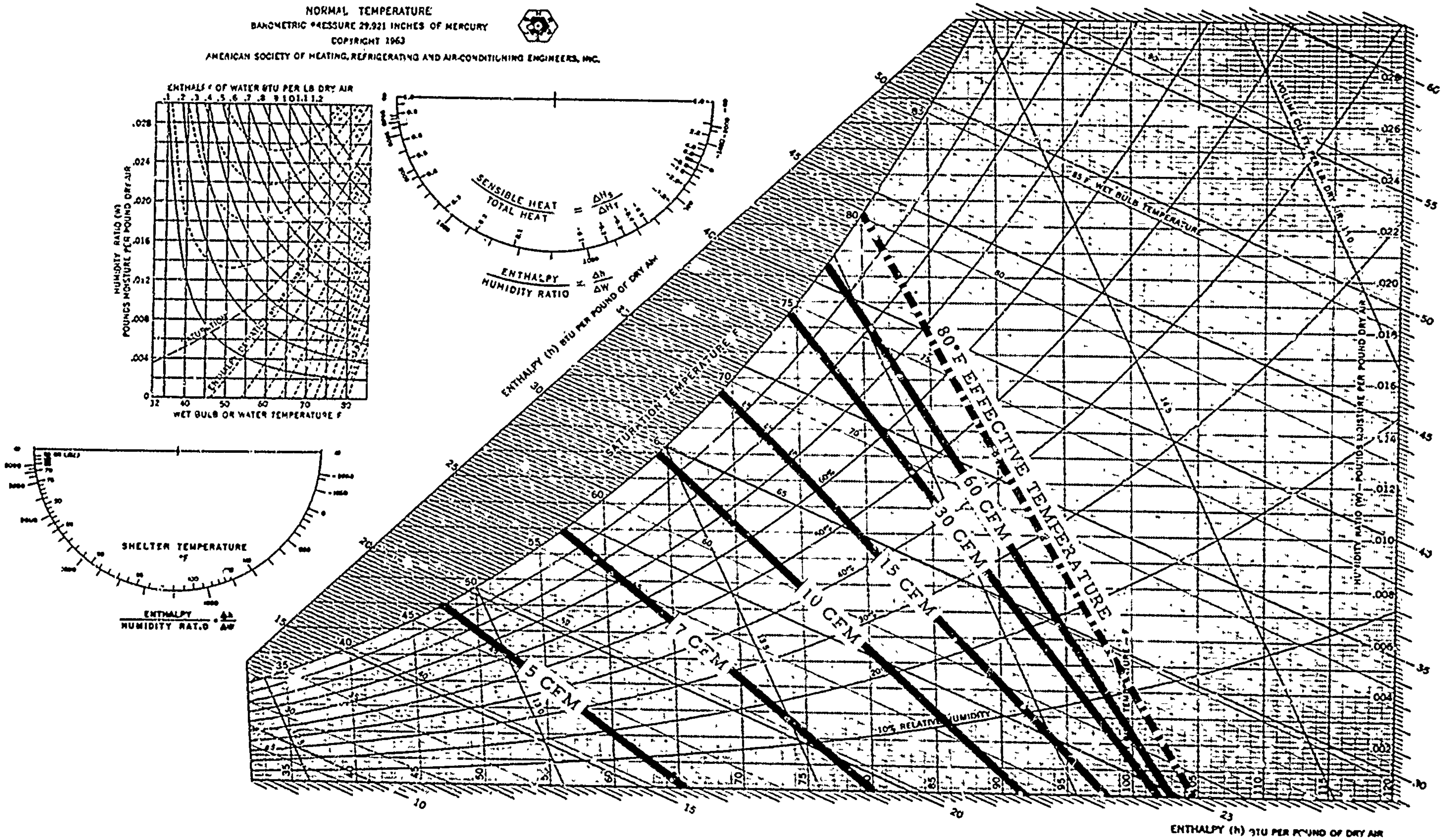

Fig. 5 VENTILATION REQUIREMENTS FOR 80°F EFFECTIVE TEMPERATURE SHELTER

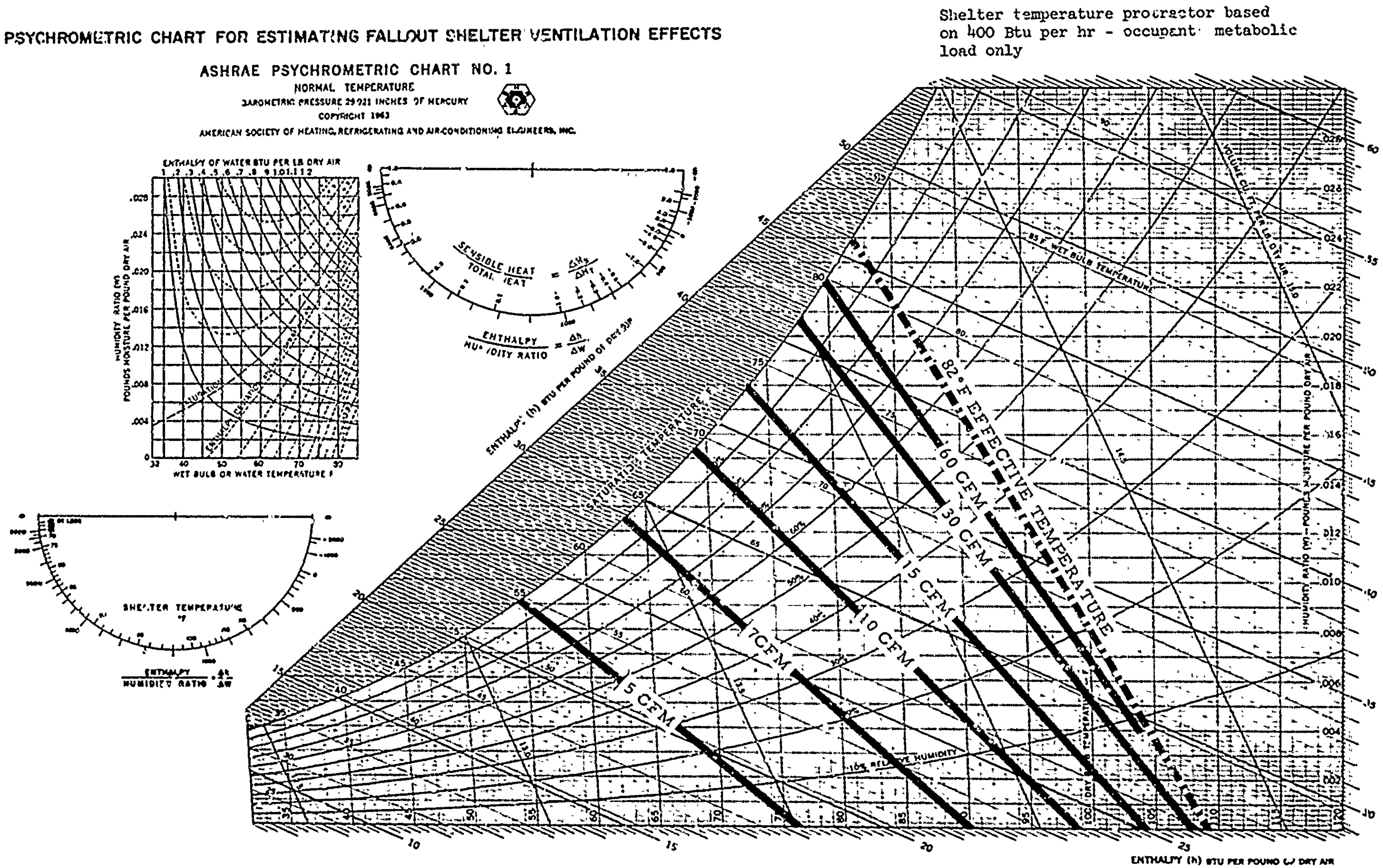


Fig. 6 VENTILATION REQUIREMENTS FOR 82°F EFFECTIVE TEMPERATURE SHELTER

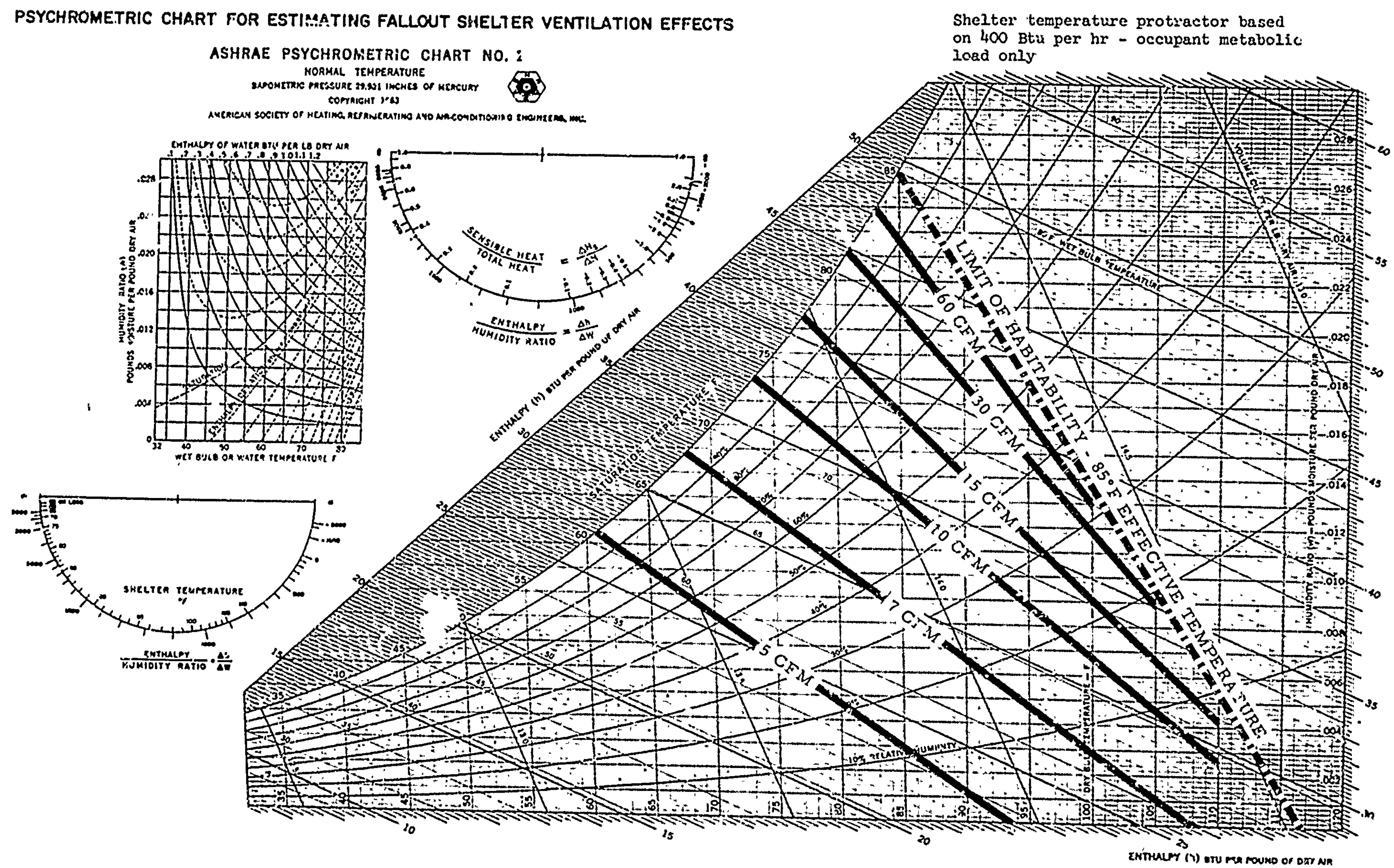


Fig. 7 VENTILATION REQUIREMENTS FOR 85°F EFFECTIVE TEMPERATURE SHELTER

heat loads. These charts may be used to determine the minimum required shelter ventilation rate per shelter occupant as follows:

1. Select the limiting shelter effective temperature: 80, 82, or 85°F.
2. Locate the point on the psychrometric chart which represents a <u>24-hour average of the inlet air dry-bulb and dew point temperature</u> (or wet-bulb temperature).
3. Read the required ventilation rate in cubic feet per minute per shelter occupant.

Neglecting wall heat losses greatly simplifies the determination of the shelter conditions. Using 24-hour average inlet conditions results in an overestimate of the 24-hour average shelter conditions, provided that all energy sources within the shelter are included in the analysis (Ref. 7).

For partially or completely belowgrade shelters, a reduction in required ventilation rate may be possible because of heat transfer to cool soil-backed surfaces. Since soil composition around identified shelters is almost impossible to predict, this heat sink must not be considered unless reliable soil information is available.

The shelter diurnal dry-bulb and effective temperature cycles follow ambient cycles, at amplitudes from 15 to 50 per cent of the ambient cycle, depending on the ventilation rate and heat storage mass exposed to the shelter air. Considerable research is needed to determine the physiological response to cyclic effective temperature.

Adequate natural ventilation of most aboveground shelters will probably be possible. This will be the subject of a future report under this contract.

Recent GARD analytical sh[illegible]r studies have indicated that the adiabetic model may not be the limiti[illegible]se. For a shelter in a light-constructed building, solar radiation on the shelter walls may during extreme weather conditions raise the shelter dry-bulb and effective temperatures above those predicted by the adiabatic model. Present work is directed toward further definition of this effect.

## REFERENCES


1. The following GARD Interim Reports, prepared under Contract OCD-OS-62-134, Subtask 1214A:

   A. Report MRD 1195-52, "Ventilation Test of an Identified Basement Shelter in Houston, Texas", January 1963.

   B. Report MRD 1195-53, "Ventilation Test of a 330-Man Aboveground Shelter in Chicago, Illinois", June 1963.

   C. Report MRD 1195-54-1, "Summer Ventilation Test of a Corridor-Type Fallout Shelter in Milwaukee, Wisconsin", September 1964.

   D. Report MRD 1195-54-2, "Summer Ventilation Test of 200-Occupant Basement Shelter in Milwaukee, Wisconsin", April 1964.

   E. Report MRD 1195-55-1, "Ventilation Test of a 210-Man Aboveground Fallout Shelter in Wilmington, North Carolina", February 1964.

   F. Report MRD 1195-55-2, "Ventilation Test of a 200-Man Belowgrade Fallout Shelter in Wilmington, North Carolina", April 1964.

   G. Report MRD 1195-56-1, "Summer Ventilation Test of an Aboveground Shelter in Bozeman, Montana", November 1964.

   H. Report MRD 1195-57, "Environmental Conditions During a 300-Occupant Shelter Test in Athens, Georgia", November 1964.

2. GATC Interim Report MRD 1268-30, "Ventilation Test of a 500-Man Basement Fallout Shelter in Providence, Rhode Island", prepared under SRI subcontract B-64220(4949A-16)-US, March 1965.

3. GATC Report MRD 1191-2, "Operation and Maintenance Manual for OCD Shelter Test Equipment", Volumes 1 and 2, prepared under Contract OCD-OS-62-99, December 1963.

4. Ibid., Volume 3.

5. G. Engholm, "A Simplified Method for Predicting Shelter Ventilation Requirements", Environmental Engineering for Fallout Shelters, Office of Civil Defense, TR-23, June 1964.

6. "ASHRAE Guide and Data Book - Fundamentals and Equipment (1963)", published by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, New York, N.Y.

7. G. Engholm, "Physiological and Meteorological Aspects of Shelter Ventilation", a paper presented at the Scientific Working Party of the NATO Civil Defense Committee meeting, June 29-July 2, 1965, Paris, France.

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13. ABSTRACT

The results of two years' field testing of fallout shelters are reported herein. Simulated occupants (Simocs) and forced flow conditioned air were used to duplicate emergency environmental conditions. Nine tests have previously been documented in detailed Interim Reports. Based on field measurements of temperature, humidity and heat flux, and supplemented by an analytical computer program, an "adiabatic" procedure is recommended to predict shelter environmental conditions. This adiabatic procedure neglects heat transmission through the shelter boundary surfaces and can predict shelter effective temperatures to within 2°F. The procedure is conservative in that it will overestimate the shelter temperature for all shelters tested.

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